EXPANDING THE SEMIOTIC SCOPE OF GEOGEBRA BY TEACHING IT TO SPEAK

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Abstract

In this paper, we describe the process of integrating JavaScript coding within GeoGebra with Google's Text-to-Speech (TTS) technology, thereby equipping the software with voice synthesis features. This integration significantly enhances GeoGebra, introducing verbal communication abilities and substantially widening its semiotic range. This development allows for a richer, holistic, and varied presentation of the concepts. By adding a vocal element, the software transforms, bringing in an extra layer of interactivity and accessibility, which amplifies its educational value. Notably, this innovation supports the development of educational activities accessible to individuals with disabilities, contributing to a more inclusive learning and teaching experience in digital spaces—an increasingly growing demand in our society. By incorporating a vocal element, GeoGebra gains a humanizing touch, transforming the software from a cold machine into an engaging, supportive educational tool. This vocal feature enhances the user experience, making interactions more intuitive and responsive. This progress marks an important move towards a more flexible and inclusive educational setting, fostering inclusion and broadening GeoGebra's educational capabilities. Additionally, we showcase the practical use of this technology with two specific examples, highlighting its potential impact on mathematics education.

Keywords: accessibility, voice synthesis, JavaScript, GeoGebra

1 INTRODUCTION

As highlighted by the author of GeoGebra (Hohenwarter, 2014), as well as by other scholars (e.g., Arifah and Sugiman (2020); Doğan and İçel (2011)), GeoGebra stands out for its ability to provide an environment of multiple semiotic representations. Through its interactive tools, GeoGebra enables students and teachers to explore mathematical concepts in various ways, connecting different sign systems and promoting more profound and meaningful learning. Furthermore, GeoGebra offers an intuitive interface that facilitates communication between semiotic representations.

In the Graphics View, geometric objects can be constructed and manipulated dynamically, while in the Algebra View, their mathematical properties are expressed in symbolic language. This interconnection allows students to visualize abstract concepts concretely and vice versa, establishing a bridge between the geometric and algebraic worlds.

GeoGebra, however, is not limited to merely presenting multiple representations. The interactive manipulation of these representations is a crucial element for meaning-making. Students can experimentally formulate hypotheses, test conjectures, and explore mathematical relationships by moving objects in the Graphics View and observing changes in the Algebra View—and vice versa. This capacity for interactive manipulation fosters active and engaging learning, where students take a central role in the knowledge-construction process. Through experimentation and investigation, they can discover mathematical properties independently, develop geometric intuitions, and strengthen their understanding of concepts.

According to Tan et al. (2021), Text-to-Speech (TTS) technology, which converts text into synthetic speech, has experienced significant growth in recent years. Several factors, such as the increasing demand for more natural and accessible human-machine interfaces, the evolution of artificial intelligence, and the proliferation of digital platforms, drive this expansion. TTS technology offers various advantages, including **Accessibility** (enables people with visual impairments or dyslexia to access content more autonomously). **Efficiency** (increases productivity by allowing people to consume information while performing other tasks). **Personalization** (enables the creation of personalized experiences with distinct voices and speech styles).

TTS technology is utilized across various platforms, such as:

- **Virtual assistants**: Smartphones, smart speakers, and other devices use TTS to provide information and perform tasks.
- **E-learning systems**: Online teaching platforms use TTS to convert text into audio, facilitating language learning and other types of content.
- **Translation services**: Online translation tools use TTS to reproduce the pronunciation of words in different languages.
- **Entertainment content**: digital books, podcasts, and audiobooks use TTS to offer users an immersive listening experience.

The expansion of TTS technology across different platforms demonstrates its potential to transform how we interact with information and the world around us. We can expect TTS to become even more sophisticated, natural, and integrated into our daily lives.

2 GeoGebra, JavaScript, and Google's TTS Service

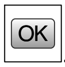
GeoGebra currently offers three programming systems: GeoGebraScript (for programming beginners), JavaScript, which became more potent with version 6 of the software as it was entirely implemented in this language, and, more recently, the Python language, which is accessed externally: `https://www.geogebra.org/python/`.

JavaScript is a programming language that allows web pages to actively transcend the mere presentation of information, becoming dynamic and interactive experiences. It powers animations, form validations, games, and complex web applications. Its versatility and ease of learning make it a powerful tool for developers, from beginners to experienced ones. The active JavaScript community provides support and resources, facilitating the creation of innovative and customized solutions Flanagan (2020).

Using artificial intelligence technology, Google's Text-to-Speech (TTS) is a free service that converts text into natural speech. It supports various languages, including English, French, Spanish, German, Portuguese, and so on, and can be integrated into web applications through JavaScript. This integration opens doors for verbalizing content in GeoGebra software, expanding the possibilities for representation and accessibility. By combining Google's TTS with GeoGebra, we can generate a new representation layer(verbal-auditory) for geometric elements, mathematical constructions, and usage instructions. It benefits different audiences, such as students with visual impairments (verbalization facilitates the understanding of visual content, promoting inclusion and autonomy for these students); students with reading difficulties (hearing the content complements reading, reinforcing understanding and learning); users who prefer information in an auditory format (verbalization allows the use of GeoGebra in situations where visual reading is hindered, such as in outdoor activities or during travel).

3 A Step-by-Step Tutorial to Make GeoGebra Speak

Here, we will present a straightforward example to explain the basic implementation principles better, but it can be adapted to any other element, whether pressed, dragged, or modified. In our example, we will create a button that, when pressed, will make GeoGebra say, "Welcome to GeoGebra!"

Step 1: From the Toolbar, activate the button creation tool: 

.

Step 2: Click anywhere in the Graphics View where you want to position the button. In the window, enter the text you want to display as the button's label. For example, set the caption to 'Speak!', press the 'OK' button, and the window will close.

Step 3: Place the mouse pointer over the newly created button, right-click, and choose the "Properties…/Settings" option.

Step 4: Click on the "Scripting" tab, and then on the "On Click" tab. **Important**: In the dropdown menu, change the option from "GeoGebraScript" to "JavaScript"! Then copy and paste the following three lines of JavaScript code:

```
var msg = new SpeechSynthesisUtterance();
msg.text = "Welcome to GeoGebra!"; // Specify here  the string to be
    spoken.
window.speechSynthesis.speak(msg);
```

The Scripting option must be 'JavaScript' and not 'GeoGebra Script'! To close this property/configuration modification window, click the small 'x' in the upper right corner. **Caution**: The correct quotes for strings in JavaScript are double quotes (") or single quotes ('), but typographic quotes (“ and ”), commonly used in text editors like Word and PDF files, can cause an error.

Important technical note: Whether in version 5 or 6 of GeoGebra, you must export your construction to HTML to hear the spoken content. This is due to a recent restriction imposed by the GeoGebra developers. To export to HTML in GeoGebra 6.0, follow this procedure(see Figure 1):

i) Click on the hamburger icon (formed by three short horizontal lines) at the upper right corner of the main interface.

ii) Choose the option "Download as..."

iii) Then, select the option "Web page (.html)".

iv) Specify a location and a filename.

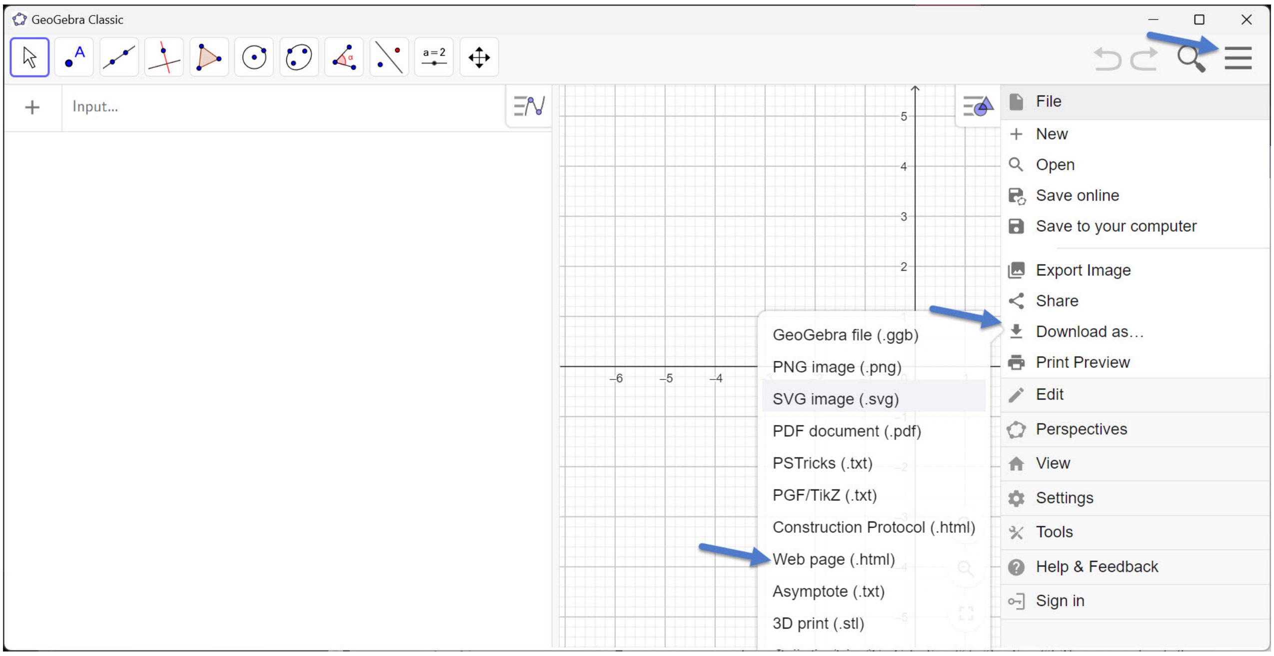


Figure 1. Downloading a construction as an HTML file in GeoGebra 6.0.

Done! The generated file can be opened locally or uploaded to a web server (your own, your school's, etc.). This HTML file includes full JavaScript features, including text-to-speech capabilities!

4 Two Examples

We will now present two examples constructed by the authors that use voice synthesis for educational purposes. The first example (Figure 2 , available at `https://www.im-uff.mat.br/nagj/jct/`, (remember to open it with Google Chrome for better results) presents a construction where the student can move the three vertices of a triangle on a rectangular, isometric, or polar grid. When the student finishes dragging one of the three vertices, the construction provides a classification in written text and verbally via TTS. Note that this GeoGebra construction is a digital counterpart of the Geoboard, a concrete artifact frequently used in teaching geometry. The construction can be used to:

- Exercise the classification of triangles based on their sides and internal angles;
- Practice coordinates in analytic geometry in the plane.

The didactic approach proposed here involves making the student construct different possible combinations of triangles, recording the coordinates of their vertices, and calculating their side lengths.

The process includes creating scalene right triangles, isosceles right triangles, and other types of right triangles, etc., while documenting the coordinates of the vertices and the lengths of the sides of the triangles. Compared to the classic Geoboard, the GeoGebra construction offers immediate feedback to the student in both textual and auditory forms. Extra Hard Challenge: Is constructing an equilateral triangle on a rectangular grid possible? If yes, provide the coordinates of the vertices. If not, explain why.

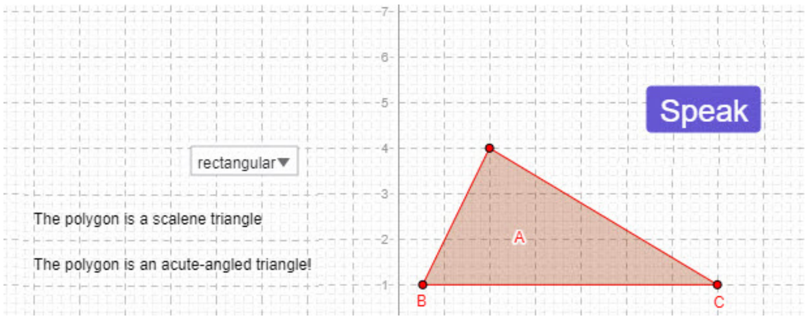


Figure 2. Classification of triangles in different meshes.

Our second example, available at `https://www.im-uff.mat.br/nagj/greek/` (See Figure 3) is a ludic construction presenting the 24 letters of the Greek alphabet widely used in mathematics. The presentation is made symbolically, in written text (the name of the letter), and verbally spoken via TTS. The TTS system is a valuable tool for students to learn how Greek letters are pronounced, enhancing their understanding of mathematical concepts. Again, we strongly recommend opening the link with Google Chrome for the best results).

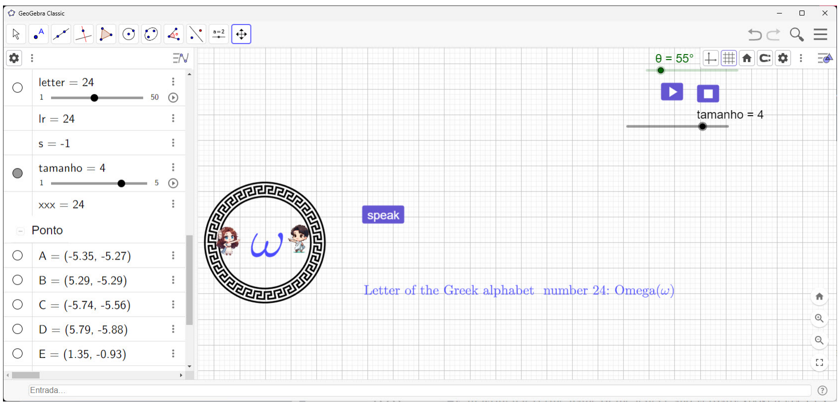


Figure 3. Learning the Greek alphabet.

5 Final Considerations

We note that, by default, each GeoGebra object triggers programming code when modified, dragged, or pressed, which may include voice synthesis calls through the presented code. Furthermore, using the GeoGebra JavaScript API, programming code can be executed even when objects are created or deleted. The ability to offer automatic sound feedback and alerts with voice synthesis allows for automatic monitoring of student interaction with the construction.

To better demonstrate the potential of the TTS feature, we present a third example (Figure 4) using the TTS feature in Basic School. The construction in Portuguese is available at `https://www.im-uff.mat.br/igi-sp/f/`. Google Chrome browser is known for its superior sound output and offers a model of a unit fraction using disks. The student can choose the number of equal parts into which the disk is divided through a slider. With this applet, the student can access a comprehensive learning experience, including a geometric and textual representation (the name of the fraction appears written in the Visualization window). With the TTS feature, the student can now also hear how the name of the unit fraction should be pronounced. Students must learn to speak and listen to the names of fractions for effective communication. A partial English version of this construction is available here: `https://www.im-uff.mat.br/nagj/f.html`.

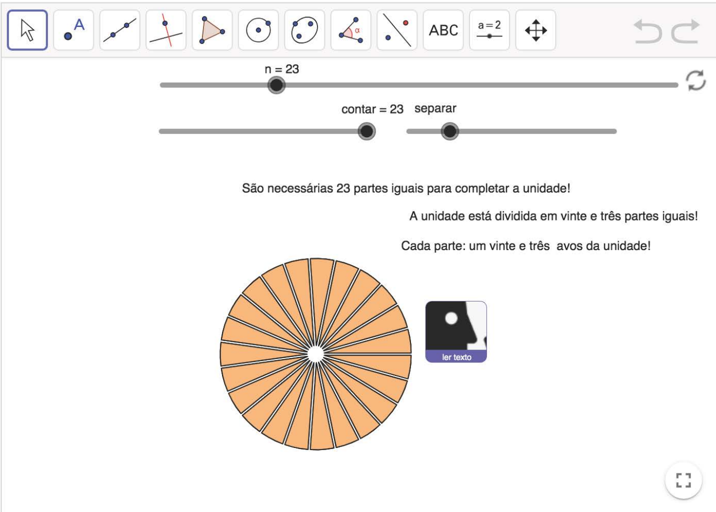


Figure 4. Unit Fractions on the Disk with Voice Synthesis (in Portuguese).

The code we initially provided assumes that the language is English. However, as our third example of fractions in Portuguese demonstrates, other languages can be used with a slightly adaptation in the JavaScript code:

```
var msg = new SpeechSynthesisUtterance();
msg.text = "Welcome to GeoGebra!"; // Specify here  the string to be spoken.

// Sets the language to US English
speech.lang = 'en-US'; // Change to pt-BR for Brazilian Portuguese, es-ES
for Spanish from Spain, fr-FR for French from France, and de-DE for
German from Germany.
// Finds and sets the voice for Portuguese, if available
speechSynthesis.getVoices().forEach(function(voice) {
if (voice.lang === 'en-US') {
// Change to pt-BR for BrazilianPortuguese, es-ES for Spanish from
Spain, fr-FR for French from France, and de-DE for German from
Germany.
speech.voice = voice;
}
window.speechSynthesis.speak(msg);
```

Dear GeoGebra user, do not be intimidated by these lines of code, which may seem daunting at first. To make GeoGebra speak, simply copy and paste the code as we indicate. However, if you delve deeper and study the JavaScript language, you will gain access to many useful features that are not available natively. To name a few: Calculate combinations of elements from a list, define recursive functions more easily, and record information and interactions with a specific construction in a Google Sheet. There are many affordable online courses on JavaScript (e.g., `https://www.udemy.com`), as well as numerous books such as Brown (2016), Alves (2020), Harrington (2021), Morrison (2008), and Yao et al. (2015).

Critical Remark: Even if in the future voice synthesis is discontinued in the official GeoGebra educational resources platform (namely, `http://www.geogebra.org`) for some reason, it will remain available as a feature of the JavaScript language. It can be accessed through the interface with the GeoGebra API for constructions embedded in local web pages (please see the context of the Figure 1). The scheme presented in this text will work when the construction is hosted anywhere **except on** `geogebra.org`.

It is worth remembering that in the context of sounds, GeoGebra has the *PlaySound* command, which allows playing audio files in mp3 format as well as waveforms defined by real functions (for more details on this feature, refer to the wiki page `https://wiki.geogebra.org/en/PlaySound_Command`.

We conclude by providing further examples of using TTS in Basic School. (Once again, the Google Chrome browser offers better voice synthesis.)

- `https://www.im-uff.mat.br/nagj/w.html`
- `https://www.im-uff.mat.br/nagj/q.html`

Remember when creating your teaching materials that any presented text can now be read using the TTS feature.

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